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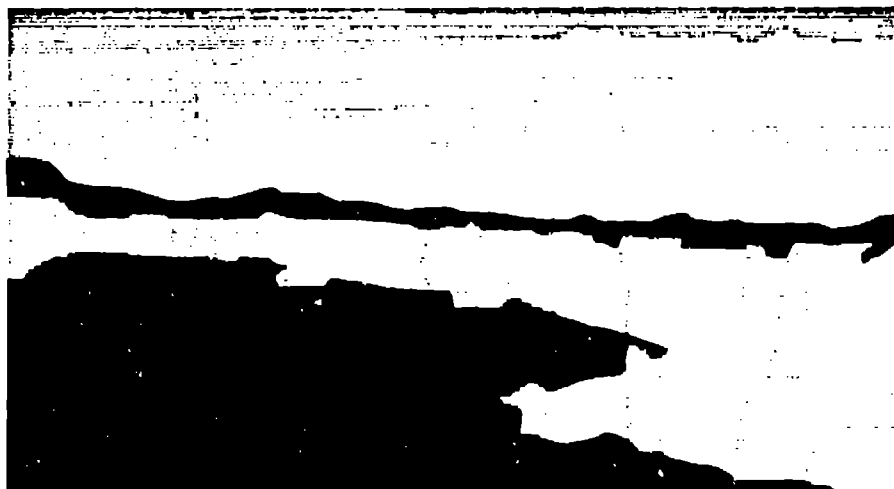
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# A LOS ALAMOS DESIGN STUDY FOR A HIGH-POWER SPALLATION-NEUTRON-SOURCE DRIVER\*

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## Abstract

A design study for an accelerator-driven spallation-neutron source is underway at Los Alamos. The driver, based on the LAMPF facility, produces a 1-MW proton beam and is upgradable to 5 MW. After linear acceleration to full energy, an  $H^-$  beam is accumulated for approximately 1 ms in a compressor ring and then extracted to produce an intense proton burst, less than 1  $\mu$ s long, onto a spallation target system with a 60-Hz cycle rate. The design uses existing infrastructure insofar as possible while maintaining project goals. This paper summarizes the system specifications and design status.

## I. INTRODUCTION

Since the construction of the Los Alamos Proton Storage Ring (PSR) [1], there has been a strong program for neutron research at the Los Alamos Neutron Scattering Center (LANSCE). The PSR was designed to provide 80 kW of beam power to the LANSCE spallation target. To furnish a possible upgrade for this facility, we have undertaken a study to delineate a system capable of delivering 1 MW of beam power to an upgraded LANSCE target with provision for a further increase in power to 5 MW. The project is known as the National Center for Neutron Research (NCNR).

The concept emerging from these studies features acceleration of  $H^-$  ions to an energy of 800 MeV and subsequent multi-turn injection into a compressor ring. The

compressed pulse is then extracted in a single turn and transported to the spallation target.

In all the studies we have stressed reliability and low beam loss as well as technical performance.

## II. GENERAL DESCRIPTION

The proposed scheme is shown in Figure 1. The existing side-coupled linac (SCL), which accelerates beam from 100 MeV to 800 MeV and comprises about 90% of the LAMPF linac, is retained as an integral part of the proposal. The present front end consists of three ion sources that provide  $H^+$ ,  $H^-$ , and polarized  $H^-$  accelerated by Cockcroft-Walton generators to 750 MeV. The three beams are merged, bunched, and matched to a 201.25-MHz drift-tube linac (DTL) for acceleration to 100 MeV. Our concept replaces the three sources with a single  $H^-$  source capable of providing 30 mA peak current at 100 keV. Beam is then matched to a 402.5-MHz radio-frequency-quadrupole linac that bunches and accelerates beam to 7.0 MeV. The next stage of acceleration is provided by a 402.5-MHz DTL to 20 MeV and subsequent acceleration by an 805-MHz DTL to 100 MeV for matching into the 805-MHz CCL. The many choices in this specification involved considerations of beam dynamics, reliability, and cost. Additionally, the configuration can be upgraded in current by funneling into the 805-MHz DTL.

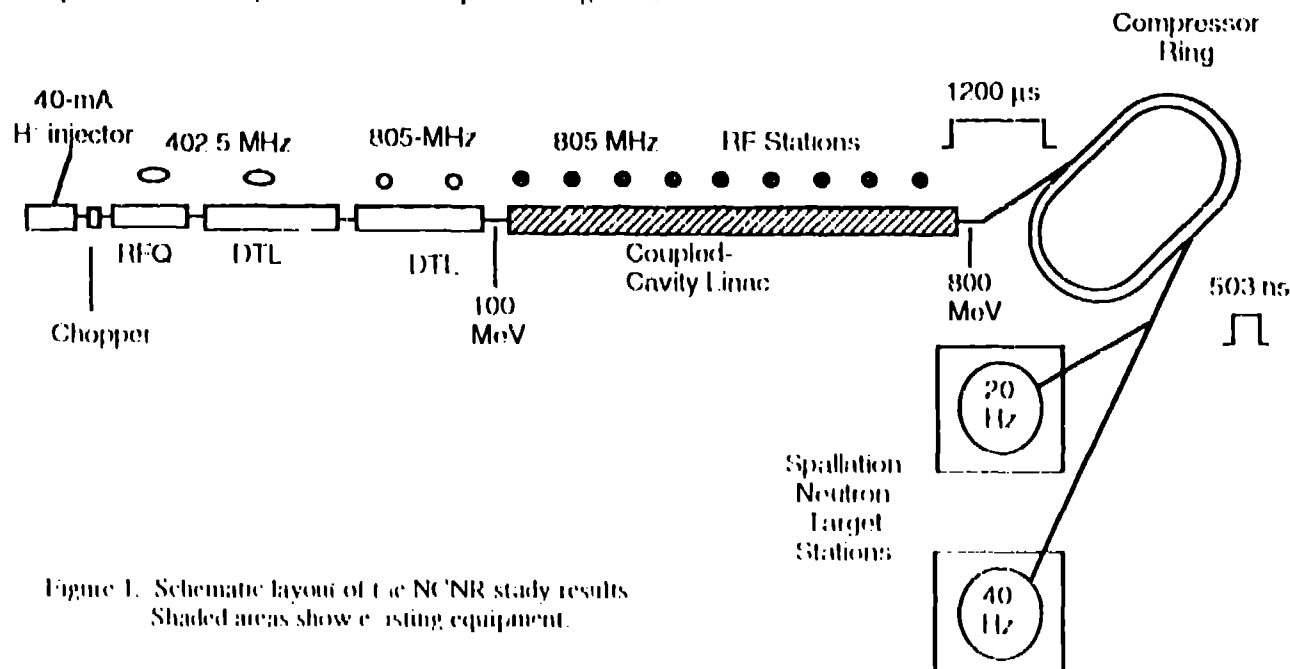


Figure 1. Schematic layout of the NCNR study results. Shaded areas show existing equipment.

An achromatic transport line takes the beam north-eastward to the compressor ring. The line also performs the function of dispersion scraping to remove off-momentum beam particles and contains magnets properly sized to avoid appreciable field stripping of the  $H^-$  beam. Beam is injected by single-stage stripping through a foil and, after accumulation for some 1790 turns, is immediately extracted. Beam is then transported to two spallation sources and inserted vertically upwards into the targets. Experiments at the neutron source generally require a regular pulse rate. Hence, pulsed equipment in the linac and ring must run at 120 Hz to provide a uniform 20 and 40 Hz to the targets.

### III. INJECTOR

Extensive development of high-current, high-brightness  $H^-$  ion sources has taken place at Los Alamos both for use at LAMPF [2] and for other projects such as the Ground Test Accelerator (GTA) [3]. We require currents somewhat above 30 mA with an rms normalized emittance of below  $0.020\pi$  cm mrad and a duty factor near 9%. No existing ion source meets all these requirements although there are several applications for which one of the requirements has been exceeded. The 4X ion source developed for GTA has produced, for example, over 60 mA at about a third of the required emittance. However, the nominal duty factor for which it has been developed is 1%. The LAMPF ion source performs with adequate duty factor and emittance but produces a current of 20 mA. These comments apply also to sources developed at other institutions. With a modest development program, it is reasonable to extrapolate to the required performance.

A more difficult problem, for which no entirely satisfactory solution now exists, is that of chopping the beam at a 1.49-MHz rate (436 ns on, 235 ns off) to maintain an extraction gap in the compressor-ring stored beam. This is currently done for the PSR by a slow-wave deflector in the LAMPF injector region at 750 keV beam energy. Such a scheme will be difficult at the low matching energy of the RFQ in the NCNR scheme. Several other options are being explored, among them fast beam switching at a source plasma electrode with modest pulsed power requirements.

### IV. LINAC

Specifications for the linac are given in Table I.

Table I  
Linac Parameters

Average current	1.4 mA
Average power	1.4 mA x 800 MeV = 1.12 MW
Peak current	30 mA
Repetition rate	20 + 40 Hz
Beam duty factor	7.2 %
Macropulse length	1.2 ms
Micropulse frequency	402.5 MHz
Chopping frequency, duty factor	1.49 MHz, 65%

The RFQ selected is similar to previous four-vane designs constructed or proposed at Los Alamos [4]. The high output energy of 7 MeV requires an unusual length of 6.9 m. The RFQ features an integral copper vacuum, rf, and structural envelope and is constructed in eight electroformed sections that are in turn electroformed together. Each pair of sections forms a loop-driven rf segment resonantly coupled to the others in a coupled-cavity structure. The average structure power is 140 kW with a peak power (including beam) of 2.1 MW. Proven tuning algorithms have been developed for this type of device. Dynamics calculations show that the structure will have over 95% transmission with an emittance of  $0.02\pi$  cm mrad (rms normalized) at 38 mA.

The 402.5-MHz DTL is designed with two tanks and a total length of 5.43 m. Permanent-magnet quadrupoles are used in an FFD configuration. Drift tube bores are 1.8 cm diameter, approximately 10 times the rms beam size. The DTL is similar to designs tested at Los Alamos on GTA and other projects. The total peak power needed is 2.03 MW. This is to be supplied by a two-tube klystron module with each tube providing a nominal 1 MW of rf power. Beam-dynamics calculations show little emittance growth with a test current of 38 mA.

The 805.0-MHz DTL is similarly constructed with a total length of 54.7 m and consists of 15 tanks. The lattice is a FF(FOOD)DDOOO configuration using 1.8 cm bore permanent-magnet quadrupoles. From our loss estimates and extensive testing of magnetic material, we do not believe that radiation-induced deterioration of the magnets will be appreciable over a period of many years. The ratio of aperture radius to beam rms size is greater than the factor of seven generally used at LAMPF as a "safe" value. Beam dynamics calculations show small emittance growth with a current of 75 mA. The total rf power required is some 8.23 MW to be supplied by a similar klystron module as used by the 402.5-MHz DTL.

Matching between the three linac sections is done transversely with variable permanent-magnet quadrupoles and longitudinally with pairs of buncher cavities. The buncher systems require a total of 60 kW of power and are supplied by six tetrode driven supplies.

Studies and experimental results have shown that the LAMPF SCL (100 to 800 MeV) is quite adequate for NCNR purposes. Note that the LAMPF facility has functioned as a provider of beam at 1 MW levels at a repetition rate of 120 Hz with a micropulse frequency of 201.25 MHz. At these levels, it operates under low stress and has had a long history of high reliability. Our proposal nearly doubles the peak current. However, the increase in micropulse frequency to 402.5 MHz results in a similar charge per beam bunch; the single bunch beam dynamics is hence unchanged. Because of the 65% chopping duty factor, the peak average current is 19.5 mA, slightly above the present nominal current of 17 mA. Taking into account the ratio of total supplied power to structure losses ( $\sim 4/3$ ), the additional average power to be supplied is some 4%, well within the present rf system reserve capacity. Hence, no substantial upgrade is needed.

A remaining question, unanswered by extensive performance tests, is the SCL response to the chopping pattern. Beam to the PSR is currently supplied at about one-third the NCNR peak-current requirement and at twice the chopping frequency with no perceived perturbation to performance. Combined structure and beam-dynamics calculations show that, under NCNR conditions, the cavity fields will vary uniformly in each tank by 4% during the chopping cycle but will have little effect on beam quality. This point will be tested in an upcoming series of experiments. Further discussion of the linac stability is found elsewhere in these proceedings [6].

Recent advances in fast adaptive feed-forward control techniques [7], proven on operating systems, will be very useful in achieving low-loss beam control in the linac and will soon be tested on the SCL. Studies are underway for high-current adaptations to tuning techniques such as the At method. Programs are also in place to study halo growth and develop techniques that minimize beam loss [8].

## V. COMPRESSOR RING

The compressor ring will be given short treatment here; it is described more extensively in an accompanying paper [9]. The major parameters are however listed in Table 2.

Table 2  
Compressor-Ring Parameters

Ring circumference	168.9 m
Accumulated turns	1790
Extracted-beam-bunch length	503 ns
Stored protons	$1.3 \times 10^{14}$
Peak stored current	57 A
Average extracted current	1.25 mA

The ring is designed in a race-track configuration as implied by Fig. 1 and has dispersionless straight sections and arcs configured as second-order achromatic bends. Injection is non-Liouvillean with a single stage foil-stripping process and has an efficiency of better than 90%. First turn losses by field stripping are minimized by placing the foil in a specially configured magnetic field. Injection painting is done to minimize foil interaction and to control the transverse distribution. This, along with an adjustable chromatic contribution to Landau damping and introduced anharmonicities, is used to control ring stability by tune-spread damping. A clean extraction gap is maintained by a five-harmonic barrier bucket to minimize extraction losses and to avoid the electron-proton instability as well as to provide adequate matching to the injected beam longitudinal phase-space structure. The injected beam is swept in energy to control the longitudinal distribution. Careful high-order studies are being done to assess space-charge nonlinearities and to map the tune space spanned by the beam. Correction of high-order stop bands and space-charge nonlinearities will be done by introduction of nonlinear elements. A continuing program of theoretical and experimental studies is underway to refine the design. Here we are particularly challenged to maintain low losses ( $< 10^{-3}$ ) and the design will include halo collimators.

## VI. UPGRADE OPTIONS

Although the major thrust of our study has been toward the 1-MW scenario, several options have been proposed for an upgrade to 5 MW and we have tried to avoid precluding these options by our design. The new linac front end is highly adaptable to funneling for increasing the current by the needed factor of 5 if a final energy of 800 MeV is retained. In this case further work is needed to establish the current-carrying capacity of the CCL and a multiple ring system would be needed.

The alternative, a higher beam energy of up to 2 GeV, is very attractive. Here a single ring, but with a substantially different lattice, appears feasible. Replacement of the CCL with a superconducting linac would use the existing LAMPF infrastructure and would ensure insensitivity to the chopping pattern that poses problems for a low-Q room-temperature structure. Studies on upgrade alternatives are continuing.

## VII. ACKNOWLEDGEMENTS

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